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The Social Construction of Technological Reality: The Case of Cochlear Implants

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ABSTRACT

This paper explores how technological trajectories and selection mechanisms are socially constructed through the interaction of a community of researchers. Using the field of cochlear implants as an illustrative case, a framework for investigating the emergence of a new technologies through the assessment of a community of researchers is developed.

INTRODUCTION

The development of new technologies can significantly affect the economic well being of both firms and nations. Among the various actors who influence the advancement of modern technology, researchers play a curious role. As scientists, they strive for objectivity in developing new knowledge, yet they cannot escape the human aspect of research communities in which they are deeply embedded in a social context that dictates a set of norms, values, and beliefs. Ultimately, some have argued, it is the subjective reality that emerges from the interaction of researchers that influences the speed and direction of technological development (Latour, 1987). The possibility that technologies are as much constructed by the social context as they are the result of the forces of nature makes research communities a critical subject of study when understanding technological emergence.

The question of who constitutes a community of researchers is more difficult then it might seem. Boundaries tend to be drawn around those individuals who are directly engaged in the development of a new technology, although such a view can be overly restrictive. A more comprehensive view might include individuals in other important roles, such as government regulators, investors, market gate-keepers, and other independent evaluators who nonetheless have an interest in the technology and its application. The influence that each of these groups have on a technology's development can depend largely

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upon their particular frame of reference, which may be quite different and oftentimes hard to reconcile.

For instance, scientists who are directly engaged in the development of a technology might be concerned most with making advances that demonstrate the superiority of their respective approaches. They pursue "technological trajectories" that are shaped by their starting assumptions and activities (Nelson and Winter, 1982; Dosi, 1982). By contrast, scientists associated with funding agencies (such as the National Institutes of Health) might encourage the exploration of different technological trajectories, while those associated with regulatory agencies (such as the Food and Drug Administration) might be concerned most with the consumer safety.

It is the complex interaction of researchers with diverse perspectives that fosters the environment in which certain technological trajectories are created and selected out. Understanding who exerts what kind of influence on a technology's development and when, may provide important insights into how new technologies emerge over time. In this paper, we examine how technological trajectories and selection environments emerge by focusing on the roles of researchers directly and indirectly associated with the development of a new technology—cochlear implants. First, we review relevant literature from the sociology of science and technology in order to introduce certain concepts that form the basis of our inquiry. Next, we explore the methodological implications of tracking the development of a new technology through the vantage point of a community of researchers. These methods are then applied to study the emergence of cochlear implant technology. Lastly, we use our findings from cochlear implants to formulate a set of general propositions regarding the development of new technologies.

THE SOCIAL CONSTRUCTION OF SCIENCE AND TECHNOLOGY

In describing the various perspectives that have been used to study the sociology of scientific communities, Crane (1972) notes the relevance of interactions between science and other social institutions: that is, how social factors shape science and how science, in turn shapes society. Jagtenberg (1983:14) points out that this "social shaping" perspective creates an artificial dichotomy between scientists and their context, because scientists themselves create the context that directs their future work. Instead of a dichotomy, Jagtenberg proposes the duality between scientists and their context, wherein the context is constituted during the course of scientific activities.

Examining the duality between scientists and their contexts implies studying science as a social system. One way the duality between scientists and their contexts unfolds is through the accumulation of knowledge. In particular, accumulated knowledge can shape intellectual patterns (Toulmin, 1963) that direct present and future scientific activities. Similarly, Kuhn (1962) proposes the notion of paradigms. Paradigms are models of scientific advancements that set guidelines for research. Kuhn distinguishes between normal science, or puzzle-solving activities aimed at exploring the limits of a paradigm, and revolutionary episodes as a model of change in science. Normal science is strongly influenced by the artifacts employed to conduct research. At first, theories direct the type of artifacts that are developed to explore phenomena. Over time, phenomena take on the appearance of objective fact by virtue of their construction through these artifacts (Latour and Woolgar, 1979). These activities continue until existing theories and artifacts are unable to explain natural phenomena. The appearance of such anomalies eventually sets in motion a chain of events that result in the development of a new paradigm.

The construction of facts and artifacts in the laboratory represents one way in which a research context is created during the process of doing science (Whitley, 1972). However, the context is also created through the interaction of scientists, thereby giving the impression that science is "negotiated." The outcome of this interaction can confer legitimacy on certain results, while disregarding others as spurious. As Latour and Woolgar (1979:243) suggest, scientific activity is not about nature, but a "fierce fight to construct reality." For Latour and Woolgar, "reality" is the consequence of the settlement of a dispute rather than its cause.

Examining science as a social system thus recognizes that context "is both medium and outcome of the reproduction of practices" (Giddens, 1979:5). This process of institutionalization represents situations where the context of research and legitimacy are constituted during the course of scientific activities. Berger and Luckmann (1967:54) state that institutionalization occurs whenever there is a "reciprocal typification of habitualized actions by types of actors." Reciprocal typification occurs as habitualized actions become embedded as routines. Over time, these routines will be taken for granted by the actors and will influence the direction of research.

The degree to which a scientific field becomes institutionalized will coincide with the degree to which scientists are able to exercise spontaneity and choice. This spontaneity and choice is progressively circumscribed as routines, equipment, skills and shared meanings that emerge through scientific activities in the contexts of research and legitimacy. At one

extreme, a high level of institutionalization implies routine thought and action; at the other extreme, minimal structures may exist, resulting in greater spontaneity and choice in research activities. Transitions from a state where the level of institutionalization is low to a state where the level of institutionalization is high represent "moments of inversion" (Latour and Woolgar, 1979:240). Moments of inversion allude to key instances in the development of science when routines, equipment, skills and shared meanings that were constituted during the process of scientific activities begin directing future scientific activities.

Building upon the insights from the study of science as a social system, a parallel literature has developed that examines the social construction of technological systems (e.g. Bijker, Hughes and Pinch, 1987; Elliott, 1988). As with scientific activities, understanding the evolution of technologies from a social systems perspective requires a recognition of the duality between technology and its applied context. For instance, Law (1988:67) suggests that "we should not assume that it is necessarily the social that molds the technological nor indeed the converse." Systems are created in the course of interactions between "heterogeneous elements" that include people, skills, artifacts and natural phenomena. People attribute different meanings to facts and artifacts based on their technological frames and their levels of inclusion (Bijker, 1987). Technological systems therefore are shaped by the differing levels of inclusion of actors within different technological frames.

The shaping of technological systems through the interaction of heterogeneous elements is analogous to the process of institutionalization in science. For researchers directly engaged in the development of a technology, this process of institutionalization manifests itself in the form of technological trajectories (Nelson and Winter, 1977; Dosi, 1982). Trajectories are progressions of a technology that are directed by researchers' initial starting assumptions and activities. Early during the development of a technology, researchers hold different beliefs about "what is feasible or at least worth attempting" (Nelson and Winter, 1982:258-59). Because of the ambiguity and uncertainty associated with technology development (Anderson and Tushman, 1990), it is not possible to *ex ante* determine the success or failure of any particular technological trajectory. Given limits to human cognition, researchers do not behave in a completely rational manner, but instead, engage in "profit-seeking" behavior. Rather than employ comprehensive search routines, researchers employ search heuristics, like genes, which are determined by researchers' starting assumptions. These search heuristics result in the development of technological

trajectories, where future progress is directed by researchers' own expectations of their trajectories.

Researchers pursue different technological trajectories and attempt to influence each other with respect to the criteria and methods against which the new technology should be evaluated. In this sense, technological systems, too, are negotiated orders. Competition between trajectories during this process of institutionalization occurs not only in the market, but also in terms of standards and testing techniques (Meyer and Rowan, 1977; Constant, 1987). Eventually, certain practices and evaluation standards are institutionalized, reinforcing some trajectories over others and thereby leading to their dominance. Once a dominant trajectory emerges, technological activities take the shape of refinements of the selected trajectories (Utterback and Abernathy, 1975).

This brief review provides certain orienting concepts that will direct our subsequent inquiry into the development of cochlear implant technology. This literature suggests that technologies evolve through a process of interaction between researchers, and that as practices and evaluation standards are institutionalized, certain technological trajectories are selected out while others are reinforced. Therefore, to study the emergence of a technology, it is important to understand how the field becomes institutionalized—before it becomes a black box, opaque to scrutiny.

METHODS AND RESEARCH SITE

A longitudinal approach is required to examine the process of institutionalization for several reasons. First, it is important to track the emergence of routines and skills before they are taken for granted by the actors involved. Moreover, a recognition of the uncertainty and ambiguity that pervades the development of a new technology renders post-hoc efficiency and functional explanations of technological trajectories inadequate. To avoid this retrospective rationality trap, it is important to provide a symmetric account of different trajectories irrespective of whether they were eventually successful or not (Pinch and Bijker, 1987).

What should the longitudinal data consist of? As the focus of this paper is on explaining how new technologies emerge over time, data should contain observations that provide insights on: (1) the direction of technical change, and (2) forces that selected out or reinforced particular trajectories. To study these issues from the perspective of an

emerging community of researchers, it is important to identify researchers' frames of references and track their levels of involvement and interactions over a period of time. To capture these diverse frames of references in any significant manner, multiple data sources are required and multiple methods have to be employed.

Our task is to demonstrate the usefulness of the concepts and methods introduced above in studying the development of a new technology. Tracking different groups of researchers longitudinally by employing multiple sources and methods can be a demanding task. Consequently, the concepts and methods suggested in this paper will be applied to study the development of only one new technology. Given this illustrative purpose, it is important to choose a strategic research site (Bijker, Hughes and Pinch, 1987). A strategic research site is one that: (1) has the potential to demonstrate the social construction of technologies, (2) is manageable, and (3) promises to bring into play diverse groups of researchers with different reference frames and motivations.

A new technology that matches these requirements is cochlear implants, which are a surgically implanted hearing devices that provide the profoundly deaf with a sensation of sound. Cochlear implants have been described as unique socio-psychological products because interpreting their effectiveness is highly user specific. Moreover, several groups of researchers have played key and visible roles in the development of cochlear implants.

Multiple sources and methods were employed on a real time and archival basis to study the development of cochlear implants. These data sources include publicly available information, articles in trade and technical journals, major entries in computer data bases, regular observations at meetings conducted by one of the leading firms in the industry, attendance at trade conferences, and periodic surveys and interviews of key industry participants. An adaptation of a data collation scheme utilized by researchers associated with the Minnesota Innovation Research Program was employed to convert the voluminous data into a form conducive to qualitative analysis (Van de Ven and Poole, 1990). Data conversion involved the identification of critical incidents consisting of: (1) events (defined as major recurrent activities and changes) and (2) observations (which were judgments or interpretive statements about events made by key researchers). From this list, incidents providing insights on researchers' roles were abstracted in a chronological order. This chronology serves as the basis for the description that follows.

The research was conducted using a qualitative case format. A case format is best suited to analyze a phenomenon in its real life context where the boundary between

phenomenon and context is not clearly defined (Yin, 1984). Moreover, a case method is useful when the objective is to generalize findings from a setting to a theory rather than from a sample to a population.

Case descriptions can be at different levels of abstraction ranging from "thick" to "abstract" descriptions (Abell, 1986; Jagtenberg, 1983:108). Thick descriptions are a researcher's first order constructions of others' constructions of what they have been up to (Geertz, 1973). In contrast, abstract descriptions constitute the first steps in the development of a theory. In this paper, we will provide an abstract description of the development of the cochlear implant field to flesh out and elaborate on the evolutionary metaphors and theoretical perspectives of the development of technological systems.

THE SOCIAL CONSTRUCTION OF COCHLEAR IMPLANT TECHNOLOGY

We examine the institutionalization of the cochlear implant field during three conceptually bracketed periods of time. These periods are: (1) a gestation period that occurred before 1978 when the cochlear technology lay dormant, (2) an institutionalization period that occurred between 1978 and 1985, and (3) an inversion period that occurred between 1985 and 1988. Each period will be discussed with reference to the evolutionary metaphors introduced earlier.

Gestation Period (before 1978). During the early years, a variety of technological approaches were pursued by researchers who were directly engaged in the development of the cochlear technology. The lack of testing, comparison and reporting standards made it difficult to compare these trajectories. Consequently, claims made by researchers about the efficacy of cochlear devices were considered to be just so much noise. Media reports sensationalized basic scientific findings thereby alienating the researcher community. Simmons, of Stanford University, remembered that one such advertisement about the miracle of the electronic ear was like claiming: "Mom gives birth to a 2 year old baby."[1] Moreover, technology champions fueled controversy surrounding cochlear implantation by invading the domains of other researchers and by publishing controversial monograms with titles such as "How to do your own implants." At the same time, audiologist gatekeepers were skeptical about the efficacy of cochlear devices in providing speech cues to the profoundly deaf when other substitutes had failed. Most researchers, including those at the NIH, had condemned human cochlear implantation as being morally and theoretically

[1]From a talk given by Blair Simmons at the NIH/FDA consensus development program held between May 2 and 5, 1988.

unacceptable. Because of this adverse selection environment, cochlear technology remained dormant for a considerably long duration of time.

Despite this adverse environment, the dedication of a few key technology champions kept the technology alive. However, while necessary, persistence by technology champions was not sufficient to ensure concerted development of cochlear implants. Some serendipitous environmental changes provided the necessary impetus for this new technology. In particular, NIH researchers decided to support cochlear implant work as a result of unrelated research activities on neural cortex stimulation initiated in Europe. This incident led to the first international conference, which was organized in 1973 at the University of California, San Francisco with support from the NIH. At this conference, researchers proposed that testing, comparison and reporting standards be developed. Standards that began emerging subsequent to the conference represented the formation of a vocabulary and grammar among a core group of researchers that legitimized the further growth of cochlear implants.

The conviction of researchers directly engaged in the development of the technology led to the creation of technological trajectories. Because of the lack of testing and comparison and reporting standards during this stage of technology development, researchers had no other choice but to continue developing their particular trajectories based on their own starting assumptions. For instance, House of the House Ear Institute (HEI) switched over from the multi-channel route to a single-channel route to better understand the cochlea before proceeding to develop more complex devices. As researchers involved in the cochlear implant area reported, no particular theoretical model of the ear directed House's research. Rather, House proceeded largely by intuition and pursued an empirical approach where he would let the results of his efforts guide his future research.

House's approach was in sharp contrast to the theoretical assumptions that guided other cochlear implant researchers. Their theories suggested that the cochlea was a complex organ that could only be replicated by the insertion of a cochlear device with multiple electrodes. In contrast to the empirical approach pursued by House and his team, the approaches pursued by these researchers had a "ring of science" attached to them.

In particular, Michelson of UCSF switched over from a single-channel device to a multi-channel device as he felt that the single-channel device would not be able to provide the same level of performance as the multi-channel device. That is, Michelson identified what Constant (1987) might call a "presumptive anomaly" with respect to the single-

channel route. A presumptive anomaly is a situation where the existing technological system still works, indeed may offer substantial development potential, but science suggests that the leading edge of future practice will have a radically different foundation. But in providing a symmetric account of the development of the different technological trajectories, the lack of testing and comparison standards made it impossible for House to clearly conclude that the multi-channel device was superior in comparison to the single-channel device. To complicate matters, the two devices aimed at different performance characteristics. While single-channel devices were designed to provide useful environmental cues, multi-channel devices were designed to provide speech perception.

These discussions suggest several insights about trajectories and selection environments during early stages of technology development. During early stages of technology development when there is a lack of a commonly accepted set of comparison and testing standards, it is difficult for researchers pursuing different technological trajectories to clearly identify deficiencies in the approaches that they adopt. Researchers pursuing different trajectories designed to provide different features will perceive their respective trajectory to be superior to others. Charges of exaggeration levied at each other therefore serve not as selection mechanisms that weaken particular trajectories, but as reinforcement for researchers' commitment to their respective trajectories in their efforts to demonstrate the validity of their claims.

Institutionalization Period (1978-1985). The pioneering researchers in cochlear implants established collaborative relationships with different business firms between 1978 and 1982. Researchers associated with firms now began to influence the development of the trajectories they had been previously chosen. For example, 3M's strategy for developing cochlear implants was to begin with the relatively safe and simple House single-channel device, which would enable the firm to create a market "window of opportunity" by being the first to obtain regulatory approvals. To accomplish this objective, 3M researchers decided not to make any core design changes in the device as design changes would take up valuable development time. However, convinced of the need to establish the safety of the device beyond any doubt, 3M researchers reduced the depth of electrode insertion. Many researchers in the industry felt that this design change reduced the efficacy of 3M's single-channel device.

This description provides a flavor of how business strategies influenced the direction of particular trajectories. This period also witnessed firms' efforts at developing testing and

reporting standards for their particular devices. Because each device embodied different features, testing and reporting standards served more to legitimize particular trajectories rather than act as selection mechanisms. Firms developed and used such standards to signal the scientific community that their particular claims were legitimate. At the same time, these testing and reporting standards reflected each firms' proprietary product attributes. That is, testing and reporting standards almost became tautological with the products they were supposed to test (Constant, 1987), with the two forming a self-reinforcing system. As a result, technical change took on a life of its own as multiple standards emerged, each confirming the expectations of the different researchers while yet not possessing the power to act as selection mechanisms.

The proliferation of tests and the difficulty in comparing test results are reflected in a statement that Gantz and his colleagues from the University of Iowa made in *Laryngoscope* in 1985.

> A major obstacle preventing accumulation of comparative data is that each center has reported results based on different measures, and in some instances investigators have developed tests tailored to their implants. (Gantz et al., 1985)

Similarly, the program manager of Storz Corporation, one of the business firms, stated in the 1986 edition of *The Hearing Journal*:

> The clinical trials allow the claims of each manufacturer to be proven. it is important that the tests be standardized. That should include both the method used to administer the tests and the type of tests used. (Quoted by Bebout in *The Hearing Journal*, 1986)

Thus, unlike the gestation period where few standards existed, standards proliferated during the institutionalization period. While earlier claims had been so much noise and hyperbole, they were now ambiguous. These claims were ambiguous as they possessed relevant cues only to those who understood or employed particular standards while being vague to others employing a different set of standards. Each firm claimed that the other was exaggerating. But given the lack of commonly accepted testing and reporting standards, it was not clear which firm was exaggerating. Claims made by firms against standards developed by them simply captured the diverse business strategies they had employed.

Researchers associated with these firms began interacting with other independent researches that entered the cochlear implant field. On the one hand, the frames of references of these independent researchers were shaped by the activities of researchers directly

engaged in the development of the products. On the other, these independent researchers also began shaping the development of the technology as they became progressively more knowledgeable and began developing a vocabulary and grammar consisting of testing, comparison and reporting standards. That is, a process of "structuration" (Giddens, 1979) ensued, resulting in a "nexus" (van den Belt and Rip, 1987) shaping the interactions between trajectories and selection environments.

While these interactions were proceeding, results of comparative tests conducted by the University of Iowa began appearing in clinical journals in 1984 (e.g. McCabe et al., 1984). These results suggested that multi-channel devices were superior to single-channel devices. Over time, other articles continued referencing results from the University of Iowa. Reflecting upon the influence that University of Iowa began having on their program, one 3M manager commented.

> People think that if an article is published, it will be forgotten after a couple of months. But, actually, other people keep on referencing this and it never really dies.

Inversion Period (1985-1988). The emergence of an institutionalized field occurred with a transition from what will be labeled as normative control, representing efforts by specific firms to shape emerging product testing/comparison standards, to coercive control, representing increasing inputs from the FDA to regulate the activities of firms (Meyer and Rowan, 1977). Representing moments of inversion, coercive control manifests itself in ever tightening regulatory guidelines for pre-market approvals.

Institutionalization led to a changing set of evaluation criteria for cochlear implants over time. Initially, researchers at the FDA felt comfortable in granting regulatory approvals to single-channel devices as the simplicity of this device facilitated their evaluation process. Moreover, the single-channel trajectory was potentially the safest approach to provide legitimacy to the new class of products. However, the demonstration of device safety was not sufficient to offer legitimacy to single-channel devices. To gain legitimacy, a device had to demonstrate efficacy—in this case, the ability to provide speech discrimination. Thus, those who pursued the single-channel route performed a yeomanry service for other more complex devices that followed by establishing the safety of the new class of product.

Another type of inversion occurred in the laboratory setting. In 1987, comparative tests carried out by independent testing institutions surfaced results that were not congruent with the theory that single-channel devices were too simplistic and could not provide speech discrimination. Based on these results, audiologists at HEI (Berliner and Eisenberg, 1987), asked the researcher community to re-examine the single-channel device with a more open mind. "We should be more open to possibilities and less tied to theory, at least until we have an objective basis for defining our expectations" suggested Berliner and Eisenberg in their article published in 1987. In this article, Berliner and Eeisenberg also stated that HEI clinicians' own initial expectations about the performance limits of the House device had led them to commit an error in not exploring the full potential of the single-channel cochlear implant. Thus, standards that had at one point in time legitimized particular trajectories later served to imprison researchers to their own expectations.

Examination of the activities of key independent evaluators demonstrate how difficult it was for them to compare and evaluate the different technologies. For instance, in assessing the different trajectories for inclusion under Medicare Feigenbaum of the Office of Health Technology Assessment stated how difficult it had been to evaluate this unique "psycho-social" therapy:

> One fascinating issue in this area is the fact that different aspects of the technology require different types of underlying methodologies to evaluate. For instance, there are speech pathologists, social scientists, audiologists and other involved. Consequently, it is very difficult to pinpoint what an 'objective scientific' method should be to evaluate the performance of a device such as the cochlear implant.[2]

What provided multi-channel devices legitimacy over single-channel devices were: (1) the theoretical rationale underlying multi-channel devices that the House single-channel device lacked, and (2) the significantly more stringent testing standards employed by researchers pursuing the multi-channel trajectory.

As standards congruent with the multi-channel device became widely accepted, signals sent out by various researchers began loosing their ambiguity. Key technology evaluators began employing standards associated with the multi-channel device, thereby vesting them with the power to act as selection mechanisms. These commonly accepted standards represented institutional selection mechanisms, which in turn triggered other selection mechanisms. For instance, audiologists interfacing with patients gave media testimonials that increased the legitimacy of multi-channel devices. Because of these testimonials,

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[2]Discussions with Earnest Feigenbaum, OHTA health science analyst held on May 12, 1988.

patients continued awaiting the availability of multi-channel devices even though FDA-approved 3M/House single-channel devices were commercially available in the market.

Acceptance of standards congruent with multi-channel devices also triggered administrative selection mechanisms. Despite signals from various sources suggesting the superiority of multi-channel devices, 3M researchers continued developing the single-channel device. A transition from the House single-channel device was made by 3M researchers directly associated with the program only when challenged by 3M top management to demonstrate the commercial viability of the House single-channel device.

While administrative selection pressures had the power to loosen the grip of technological trajectories over researchers within firms, institutional and market pressures were not adequate to dissuade researchers such as Dr. House from abandoning their trajectories. Despite various signals from institutional bodies and the market, House continued refining his single-channel device. The positive test results that independent researchers documented with single-channel devices promised to re-start a confrontation between researchers pursuing the single-channel route and those pursuing the multi-channel route. However, in performing their respective roles, researchers at the FDA and the NIH felt it necessary to institutionally induce closure by organizing a consensus development conference in 1988. It was at this two-day meeting that the evidence and impressions, which the researcher sub-communities had accumulated over time, were quickly crafted into a consensus statement that supported the superiority of the multi-channel device over the single-channel device.

A researcher at 3M offered an explanation for this outcome. According to this researcher, theory had initially driven research. However, incongruities between theoretical beliefs and clinical results had not led to a re-examination of the strongly held theoretical biases, but rather a re-interpretation of the results. In explaining the NIH/FDA consensus statement supporting the superiority of the multi-channel device, Berliner of HEI suggested that otologists were "converging to the multi-channel device in order to reduce cognitive dissonance on the choice of the most appropriate device."

DISCUSSION AND CONCLUSION

This paper began with a description of researchers embedded in a social context. To study the roles of researchers in the commercial development of a new technology,

orienting concepts such as trajectories and selection environments were introduced (Nelson & Winter, 1982; Dosi (1982). To apply these concepts to the study of a technology and provide a symmetric account of both failures and successes, a longitudinal design was suggested with a focus on researchers' frames of references to . Multiple sources and methods were suggested as an approach for gathering information on what researchers say and do that influence the development of a new technology.

Application of these methods to study the commercial development of cochlear implants suggest several theoretical insights that build upon received theory (Nelson and Winter, 1982; Dosi, 1982. The following table summarizes these insights:

	GESTATION	INSTITUTIONALIZATION	INVERSION
RESEARCH COMMUNITY CONSTITUENTS	Researchers who are directly involved with the technology's development.	Researchers affiliated with firms, regulatory and financial institutions.	Community expands to include independent testing centers and market gatekeepers.
TECHNOLOGICAL TRAJECTORIES	Early exploration and commitment to trajectories.	Need to validate claims reinforces commitment to established trajectories.	Standards blind researchers from alternative trajectories. Administrative selection mechanisms loosen grip of trajectories on industrial researchers.
SELECTION MECHANISMS	Adverse selection environment resulting from a lack of standards. Controversial debates among researchers and media distortion	Criteria fight between multiple standards that legitimize particular trajectories and result in ambiguous claims.	Transition from normative to coercive control as claims lose ambiguity and multiple selection mechanisms are sequentially triggered.

As the description highlights, technological variations occurred as researchers directly engaged in the development of cochlear implants pursued different trajectories. Researches at the NIH encouraged these technological variations by funding research activities that explored different cochlear implant approaches. In contrast, researchers at the FDA and at independent testing institutes served the role of differentially selecting out trajectories.

Institutional, market and administrative selection mechanisms were socially constituted through a process of interactions and negotiations between these different types of researchers. These selection mechanisms were activated at different periods of technology development. Each environment possessed differential power to reinforce or select out particular technologies. Institutional selection mechanisms became important with a transition from normative to coercive control as standards developed to legitimize particular technological trajectories and then became institutionalized and developed the power to select out other trajectories. These institutional selection mechanisms triggered market and administrative selection mechanisms. While the former did not loosen the hold of particular technological trajectories over independent researchers, administrative selection mechanisms forced researchers associated with firms to abandon earlier trajectories and explore new ones. Eventually, closure was institutionally induced.

These observations form the basis for the following propositions that reflect the process of institutionalization of a technological field:

PROPOSITION 1: *Before an institutionalized field emerges, the lack of any testing standards create adverse selection mechanisms that threaten the survival of the new class of technology.*

PROPOSITION 2: *During the process of institutionalization, the existence of multiple and conflicting testing standards creates ambiguity. These testing standards legitimize specific trajectories leading to reinforcing the commitments of researchers to their respective trajectories.*

PROPOSITION 3: *After an institutionalized field emerges, widely accepted testing standards differentially select out some trajectories while reinforcing others.*

What are the implications of the methodology developed and the insights gained from studying the development of cochlear implants? An understanding of researchers as social scientists raises a critical issue regarding the theoretical rationale behind the choice of trajectory that researchers choose to pursue. While, as in the cochlear implant case, it may make intuitive sense to start off with a simple trajectory and then learn from experience to build more complex ones, the lack of a strong theoretical rationale for a trajectory may prove critical in establishing its legitimacy within a researcher community.

Discussions relating to trajectories and selection mechanisms raise questions about when it is most appropriate for researchers to expose their particular trajectories to tests by

independent testing institutions. A trajectory, prematurely offered to an independent group of researchers for testing, may not be able to withstand the adverse selection pressure. On the other hand, if timely independent testing is not carried out, researchers risk the danger of loosing legitimacy for their trajectory, and more important, lose the opportunity to determine the performance capabilities of their respective trajectories.

The most important implication for the management of innovation follows from the basic premise of this paper—that different types of researchers play varied roles in determining the success or failure of a new technology or specific trajectories. What these researchers say or do can either legitimize or trigger off adverse selection mechanisms that then become key determinants of success or failure. As MacKenzie (1987:198) suggests, researchers often have little time for sociology and other social sciences. Yet researchers also know that to be successful they have to be able to engineer more than metal and equations. Or as Whitley (1974) suggests, researchers must not only manage the research context, but also the social context of legitimacy. In particular, researchers directly engaged in the development of new technologies have to deal with different types of researchers with diverse motivations and recognize the temporal dynamics such as when and to what extent particular researchers become important.

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